Slides for Chapter 15: Coordination and Agreement

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Distributed Systems: Concepts and Design

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Overview of Chapter

- Introduction
- Distributed mutual exclusion
- Elections
- Coordination and agreement in group communication (skip)
- Consensus and related problems (skip)

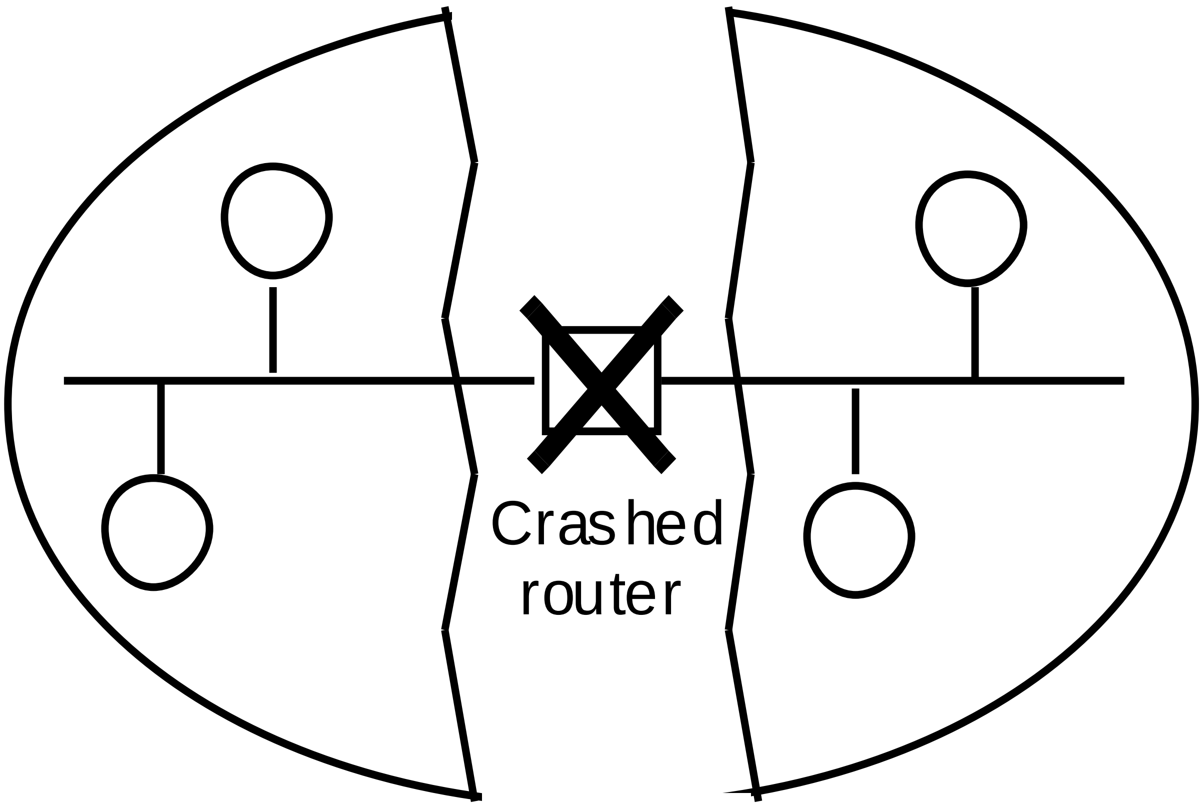
Introduction

Covers two areas:

- Coordinating actions in a distributed system
- Distributed processes agreeing on a result value

- Assumes reliable communication channels for simplicity (failure is masked by a reliable communication protocol)
- Detecting that a process has failed can be reliable or unreliable
- Use timouts
- Unreliable: replies *unsuspected* or *suspected*
- Reliable: replies *unsuspected* or *failed*

Figure 15.1
A network partition



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Distributed mutual exclusion

Known as *critical section* problem:

- Only one process can be in critical section – the process with the *token* that allows access to the resource
- Operations include the following:
- enter() – requests access; can be granted or blocked
- resourceAccess() – access resource in critical section
- exit() – leave critical section – other processes may now enter

Conditions:

- ME1 (safety) – at most one process in critical section
- ME2 (liveness) – requests eventually succeed
- ME3 (ordering) – requests follow happened-before relationship

Distributed mutual exclusion

Various algorithms:

- Central server algorithm
- Ring-based algorithm
- Algorithm using multicast and logical clocks
- Voting algorithm
- Others

Figure 15.2
Server managing a mutual exclusion token for a set of processes

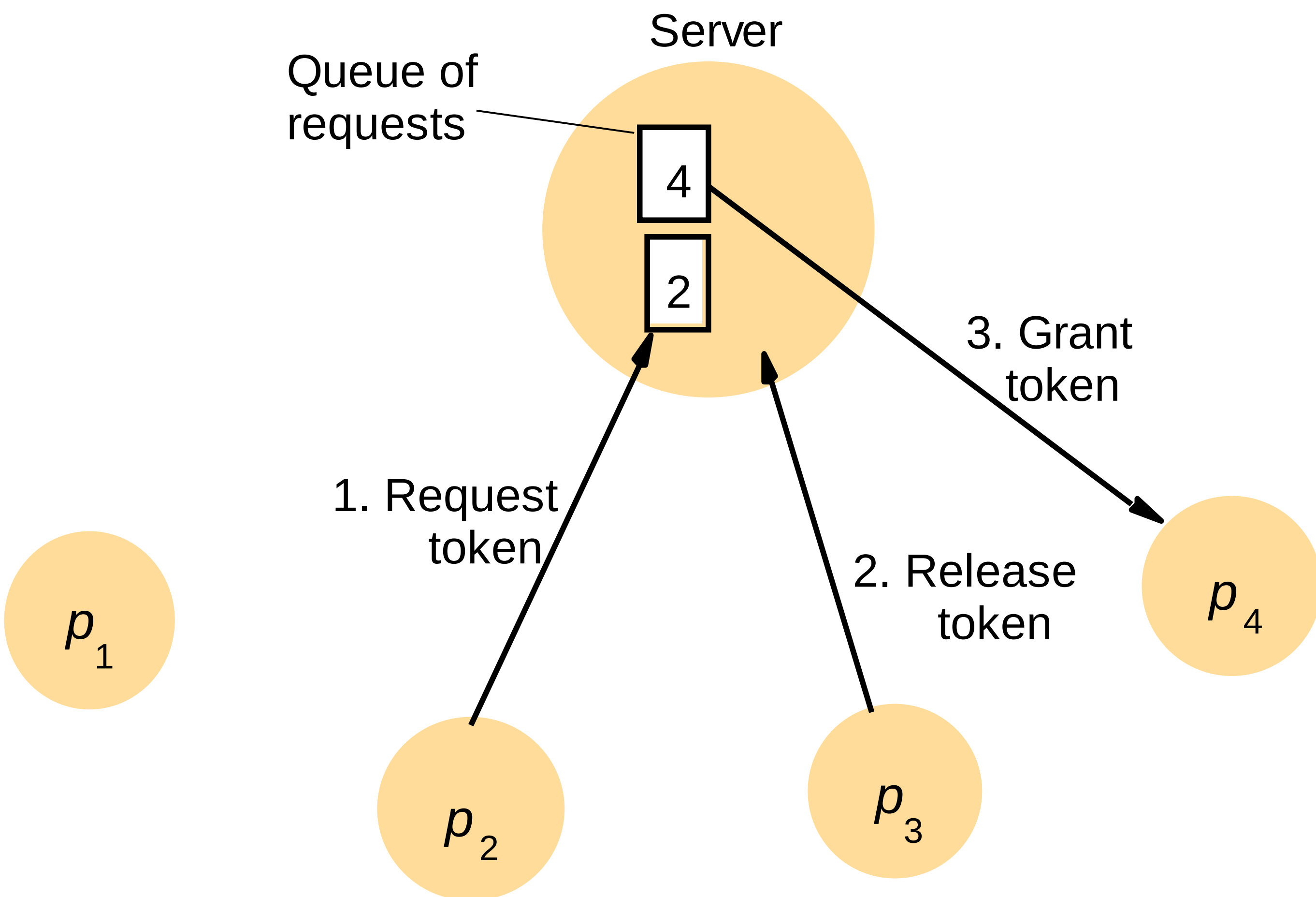

Figure 15.3
A ring of processes transferring a mutual exclusion token

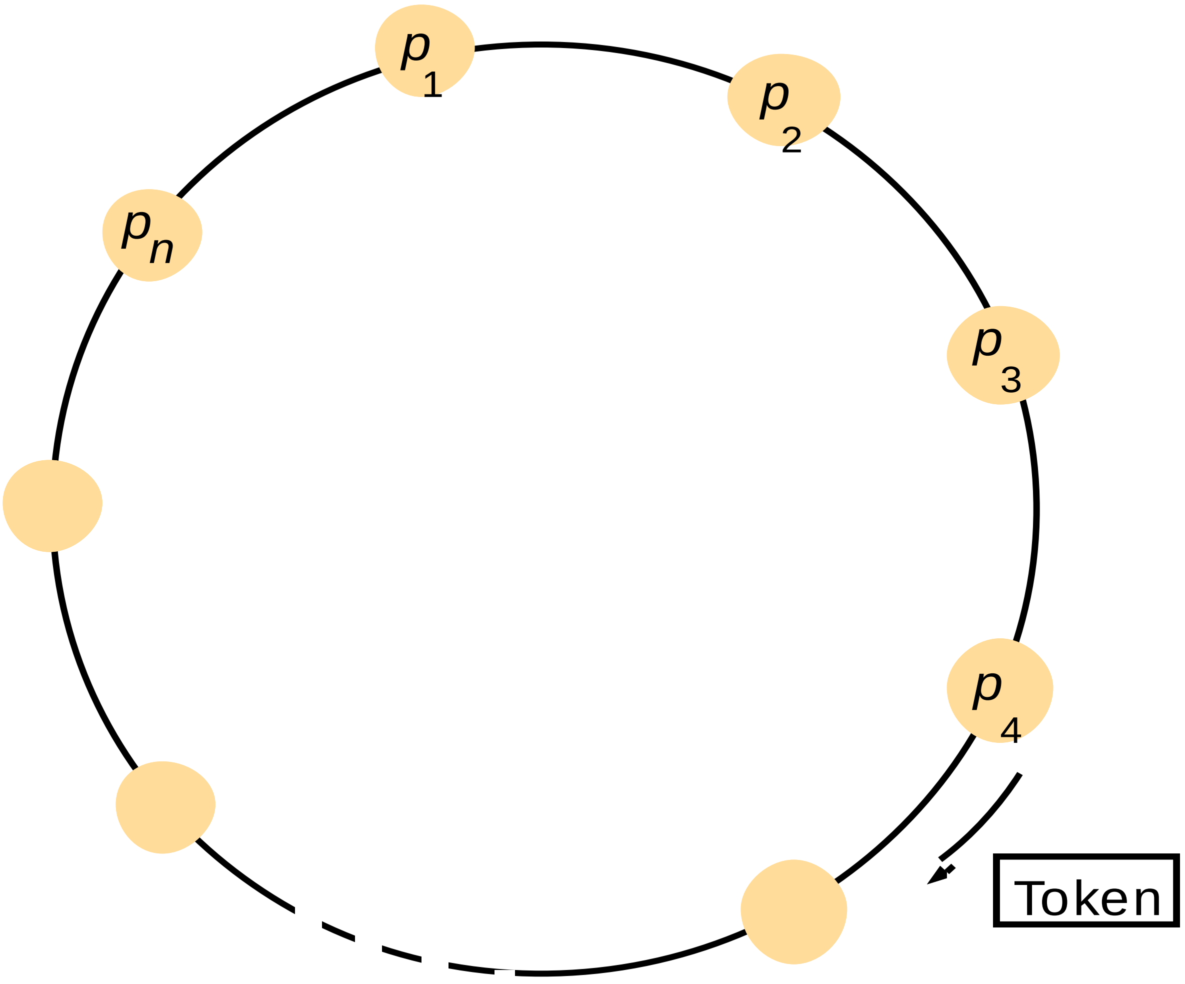

Figure 15.4
Ricart and Agrawala's algorithm

On initialization

    state := RELEASED;

To enter the section

    state := WANTED;

    Multicast *request* to all processes;

    T := request's timestamp;

request processing deferred here

    Wait until (number of replies received = $(N - 1)$);

    state := HELD;

On receipt of a request $<T_i, p_i>$ *at* p_j $(i \neq j)$

    if (*state* = HELD or (*state* = WANTED *and* $(T, p_j) < (T_i, p_i)$))

    then

        queue *request* from p_i without replying;

    else

        reply immediately to p_i;

    end if

To exit the critical section

    state := RELEASED;

    reply to any queued requests;

Figure 15.5
Multicast synchronization

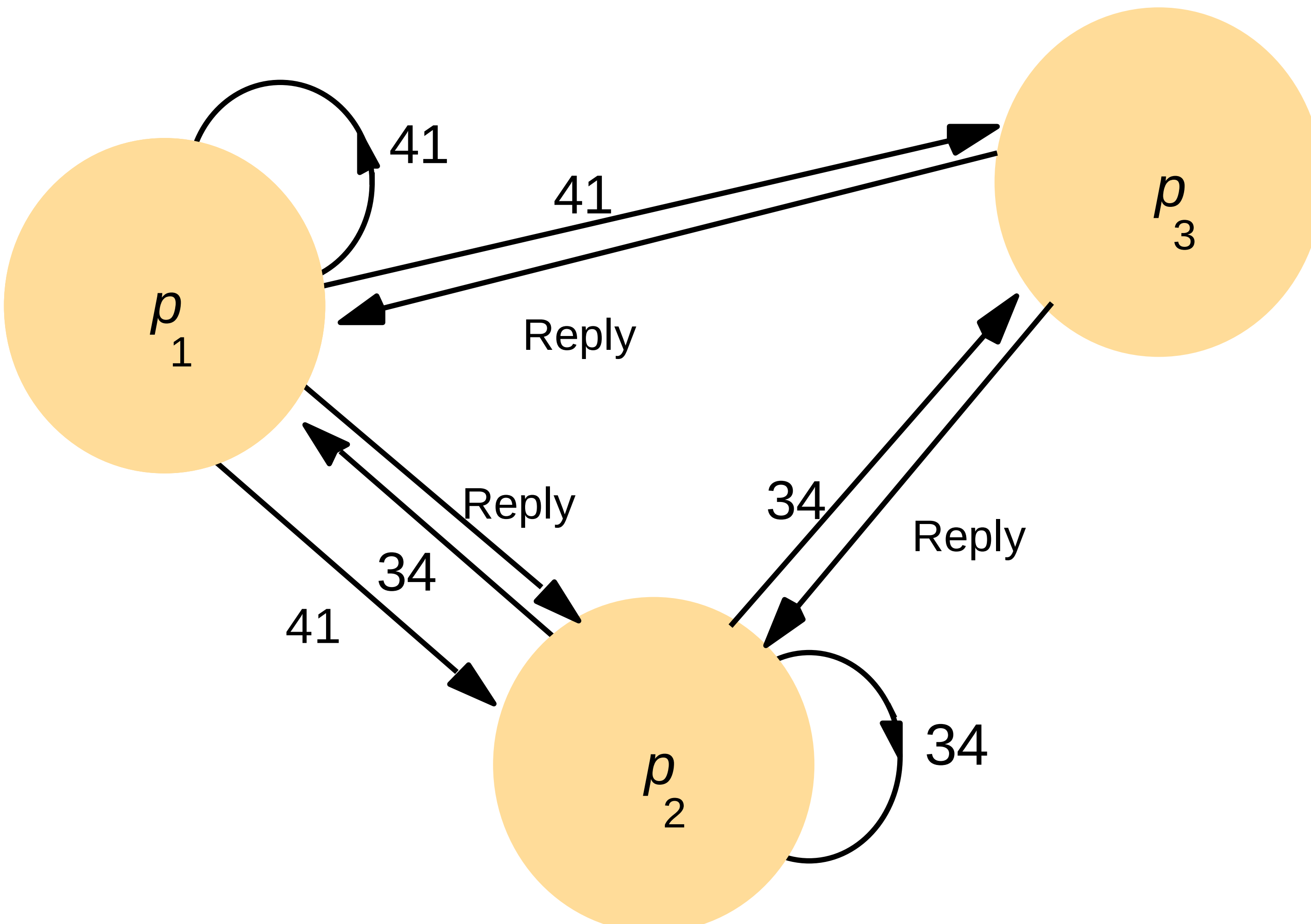

Figure 15.6
Maekawa's algorithm – part 1

On initialization
  state := RELEASED;
  voted := FALSE;

For p_i to enter the critical section
  state := WANTED;
  Multicast *request* to all processes in V_i;
  Wait until (number of replies received = K);
  state := HELD;

On receipt of a request from p_i at p_j
  if (*state* = HELD *or voted* = TRUE)
  then
    queue *request* from p_i without replying;
  else
    send *reply* to p_i;
    voted := TRUE;
  end if

For p_i to exit the critical section
  state := RELEASED;
  Multicast *release* to all processes in V_i;

On receipt of a release from p_i at p_j
  if (queue of requests is non-empty)
  then
    remove head of queue – from p_k, say;
    send *reply* to p_k;
    voted := TRUE;
  else
    voted := FALSE;
  end if

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Elections

Election algorithms:

- Used to choose a particular process for a role – for example, to choose a central server for distributed algorithms that require a central server
- Process can call an election; for example, if it detects that central server has failed

Requirements:

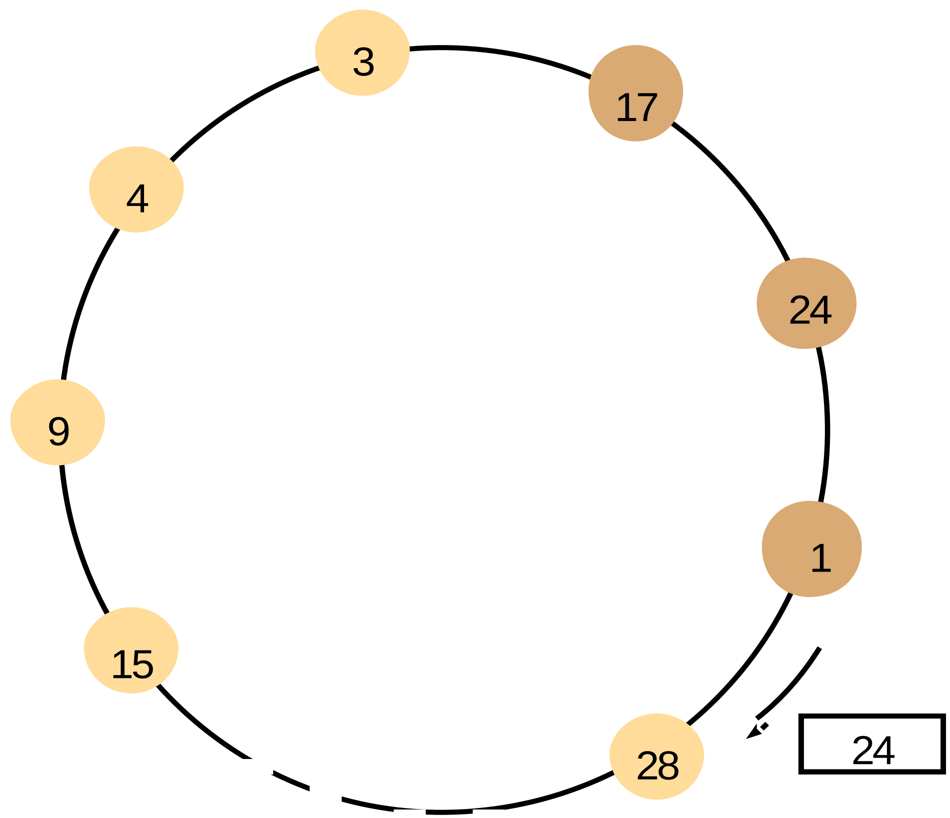
- E1: (safety) only one process is elected – each participant sets elected*i* either to P or to undefined if it does not know the elected process yet (P will be the participant with the largest process id)
- E2: (liveness) all processes participate and either set elected*i* to the elected process or crash

Elections

Election algorithms:

- Ring-based algorithm
- Bully algorithm

Figure 15.7
A ring-based election in progress



Note: The election was started by process 17.
The highest process identifier encountered so far is 24.
Participant processes are shown in a darker colour

Figure 15.8
The bully algorithm

The election of coordinator p_2, after the failure of p_4 and then p_3

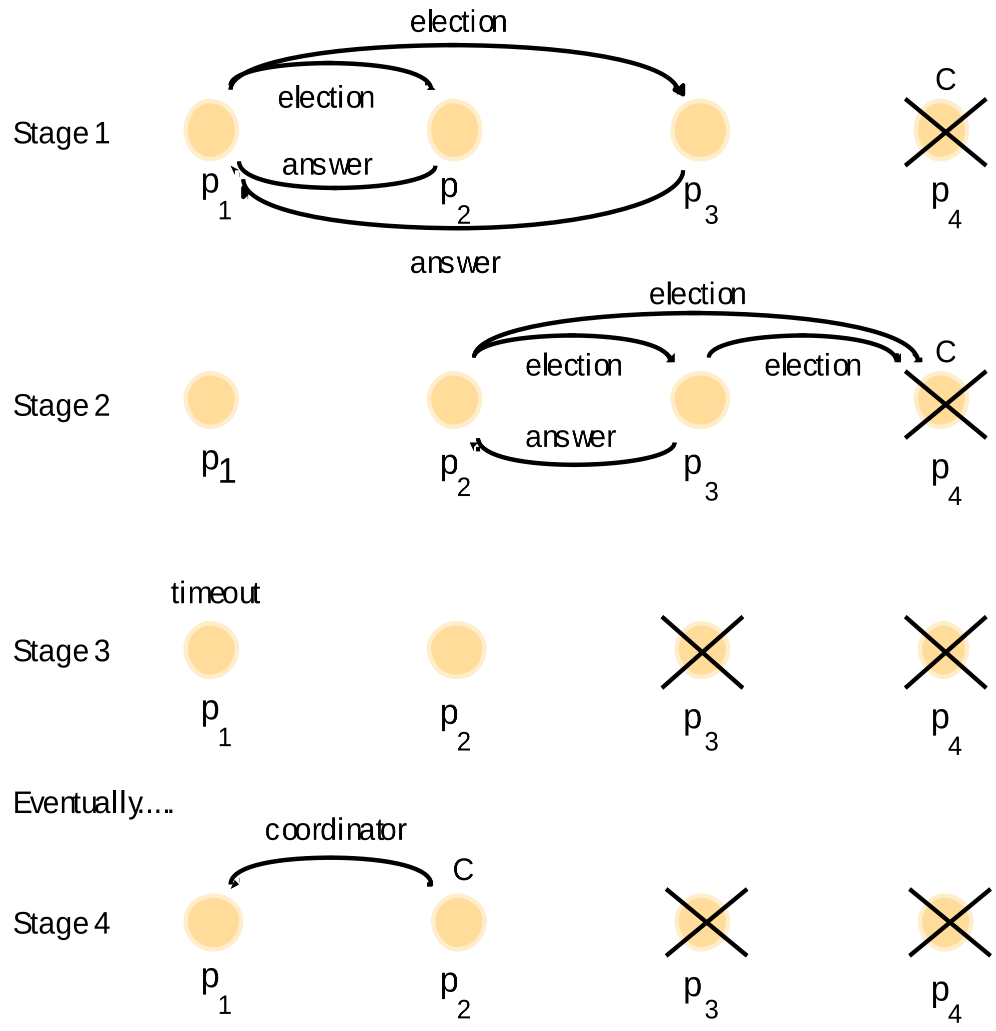


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Figure 15.9
Reliable multicast algorithm

On initialization
    $Received := \{\};$

For process p to R-multicast message m to group g
    $B\text{-}multicast(g, m);$ // $p \in g$ is included as a destination

On B-deliver(m) at process q with g = group(m)
    $if\ (m \notin Received)$
    $then$
        $Received := Received \cup \{m\};$
        $if\ (q \neq p)\ then\ B\text{-}multicast(g, m);\ end\ if$
        $R\text{-}deliver\ m;$
    $end\ if$

Figure 15.10
The hold-back queue for arriving multicast messages

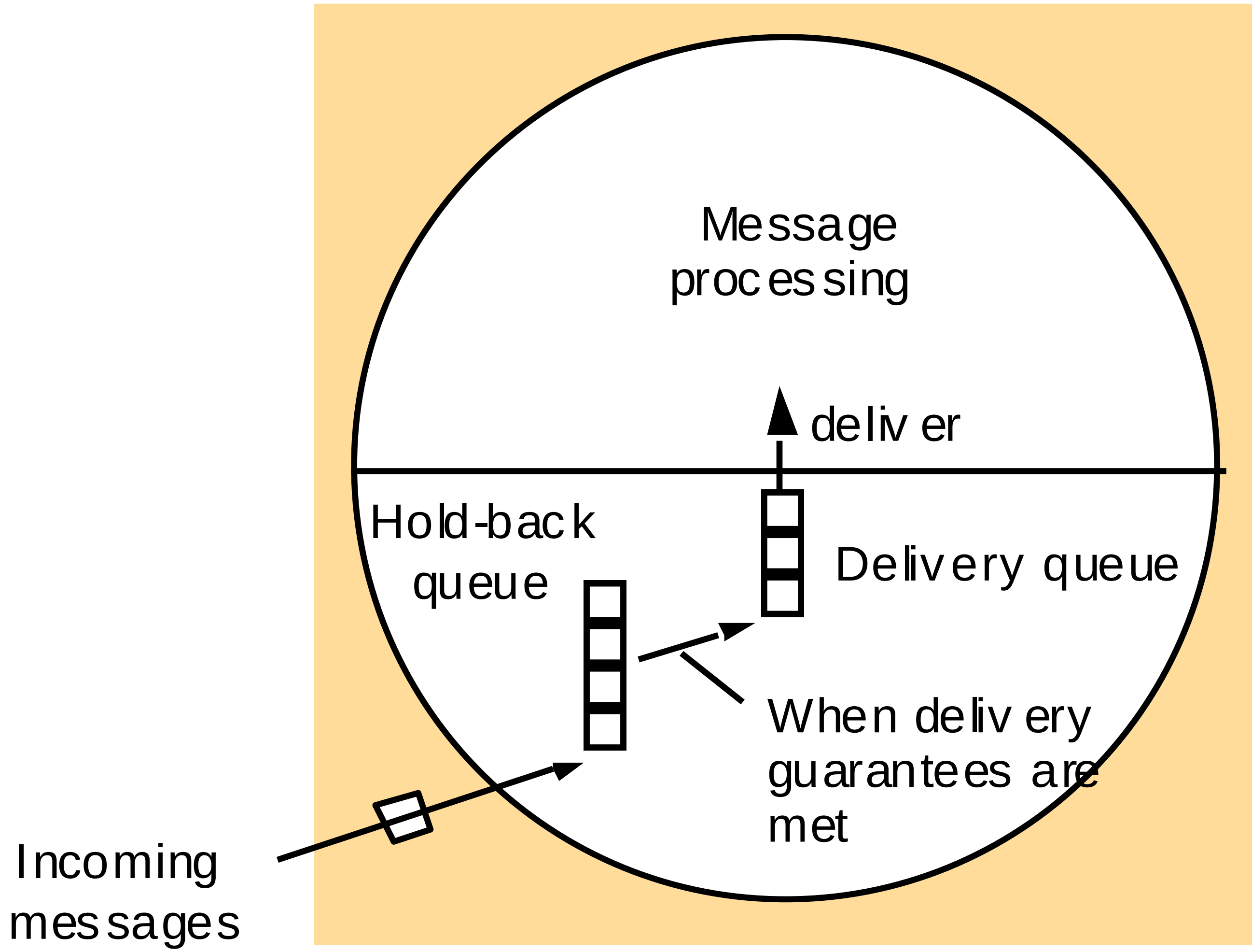


Figure 15.11
Total, FIFO and causal ordering of multicast messages

Notice the consistent ordering of totally ordered messages T_1 and T_2, the FIFO-related messages F_1 and F_2 and the causally related messages C_1 and C_3 – and the otherwise arbitrary delivery ordering of messages.

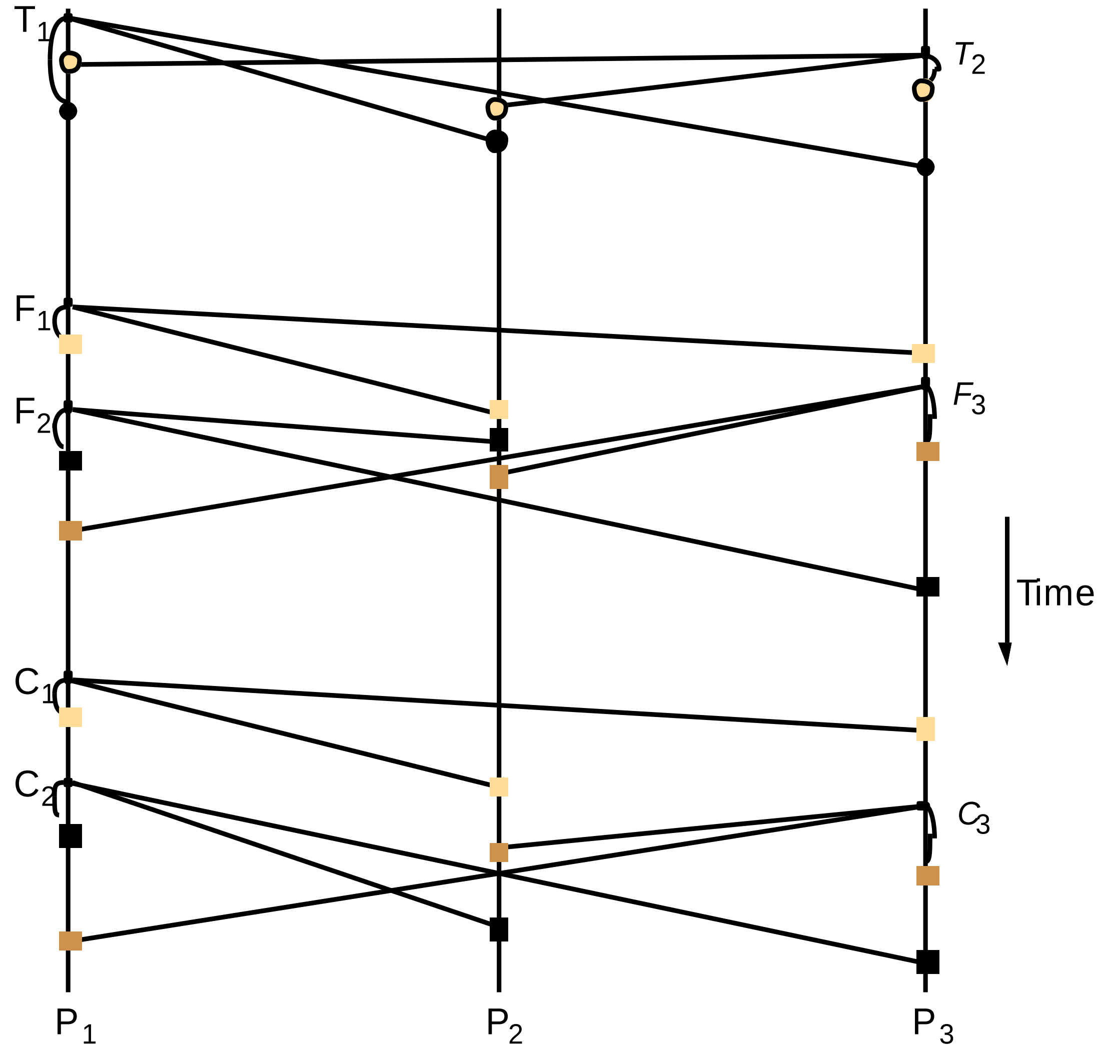


Figure 15.12
Display from bulletin board program

Bulletin board: os.interesting		
Item	From	Subject
23	A.Hanlon	Mach
24	G.Joseph	Microkernels
25	A.Hanlon	Re: Microkernels
26	T.L'Heureux	RPC performance
27	M.Walker	Re: Mach
end		

Figure 15.13
Total ordering using a sequencer

1. Algorithm for group member *p*

On initialization: $r_g := 0$;

To TO-multicast message m to group g
  B-multicast$(g \cup \{sequencer(g)\}, <m, i>)$;

On B-deliver$(<m, i>)$ *with* $g = group(m)$
  Place $<m, i>$ in hold-back queue;

On B-deliver$(m_{order} = <\text{“order”}, i, S>)$ *with* $g = group(m_{order})$
  wait until $<m, i>$ in hold-back queue and $S = r_g$;
  TO-deliver m;   // (after deleting it from the hold-back queue)
  $r_g = S + 1$;

2. Algorithm for sequencer of *g*

On initialization: $s_g := 0$;

On B-deliver$(<m, i>)$ *with* $g = group(m)$
  B-multicast$(g, <\text{“order”}, i, s_g>)$;
  $s_g := s_g + 1$;

Figure 15.14
The ISIS algorithm for total ordering

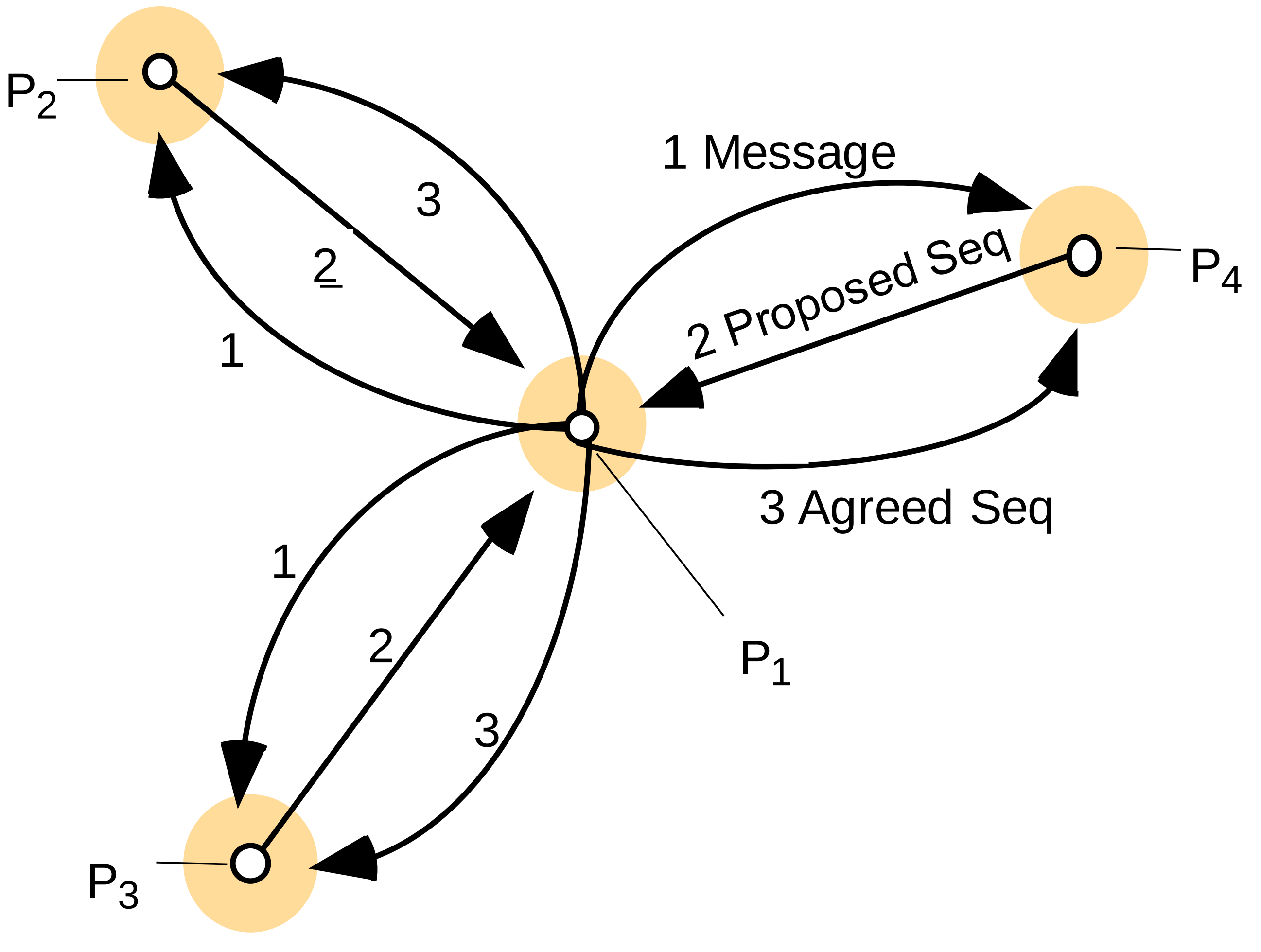


Figure 15.15
Causal ordering using vector timestamps

Algorithm for group member p_i $(i = 1, 2 \ldots, N)$

On initialization

$V_i^g[j] := 0 \ (j = 1, 2 \ldots, N);$

To CO-multicast message m to group g

$V_i^g[i] := V_i^g[i] + 1;$

$B\text{-}multicast(g, < V_i^g, m >);$

On B-deliver$(< V_j^g, m >)$ *from* p_j, *with* $g = group(m)$

place $< V_j^g, m >$ in hold-back queue;

wait until $V_j^g[j] = V_i^g[j] + 1$ and $V_j^g[k] \le V_i^g[k] \ (k \ne j);$

CO-deliver m; // after removing it from the hold-back queue

$V_i^g[j] := V_i^g[j] + 1 \, ;$

Figure 15.16
Consensus for three processes

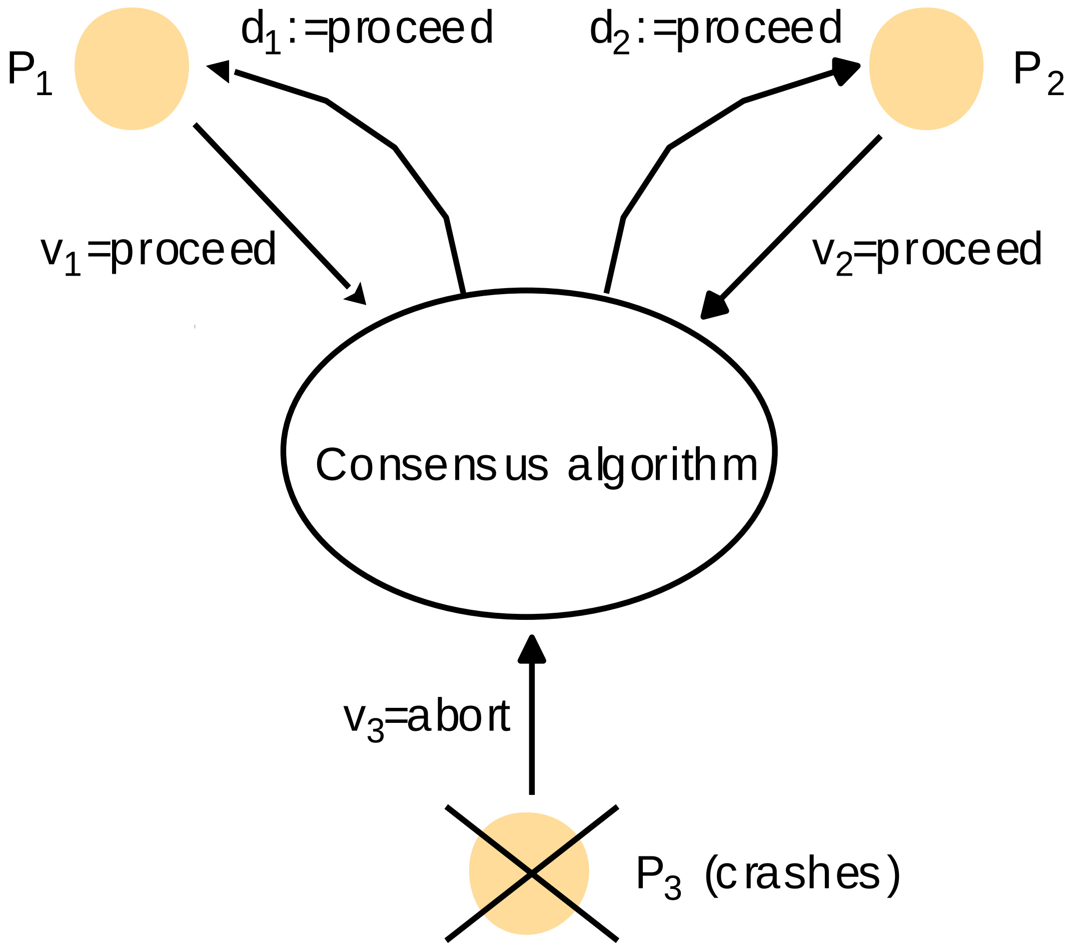


Figure 15.17
Consensus in a synchronous system

Algorithm for process $p_i \in g$; algorithm proceeds in $f + 1$ rounds

On initialization

$Values_i^1 := \{v_i\}$; $Values_i^0 = \{\}$;

In round r $(1 \le r \le f + 1)$

$B\text{-}multicast(g, Values_i^r - Values_i^{r-1})$; // Send only values that have not been sent

$Values_i^{r+1} := Values_i^r$;

while (in round r)

{

On B-deliver(V_j) *from some* p_j

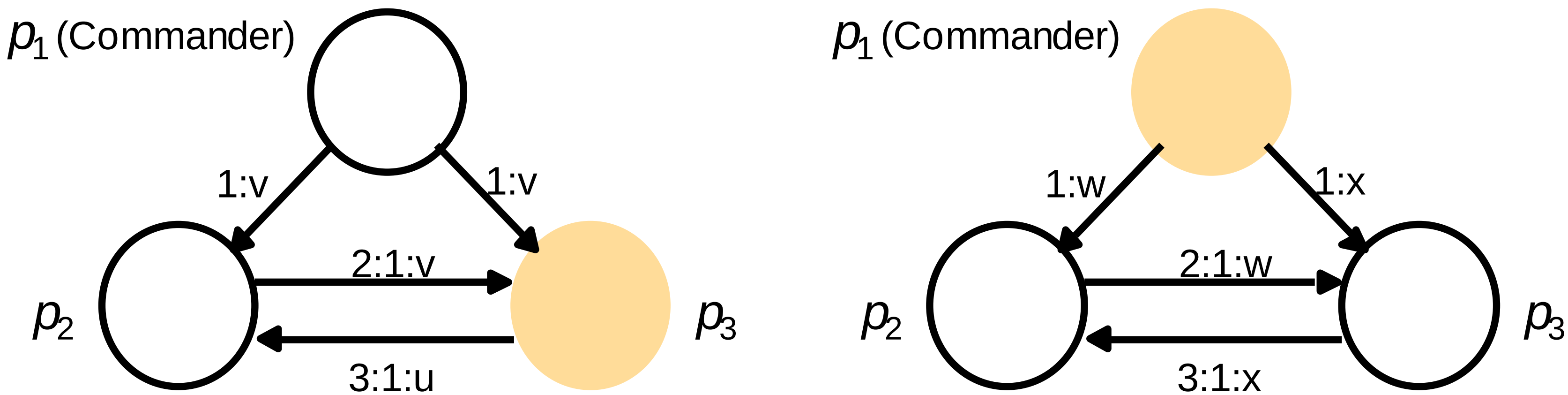
$Values_i^{r+1} := Values_i^{r+1} \cup V_j$;

}

After $(f + 1)$ *rounds*

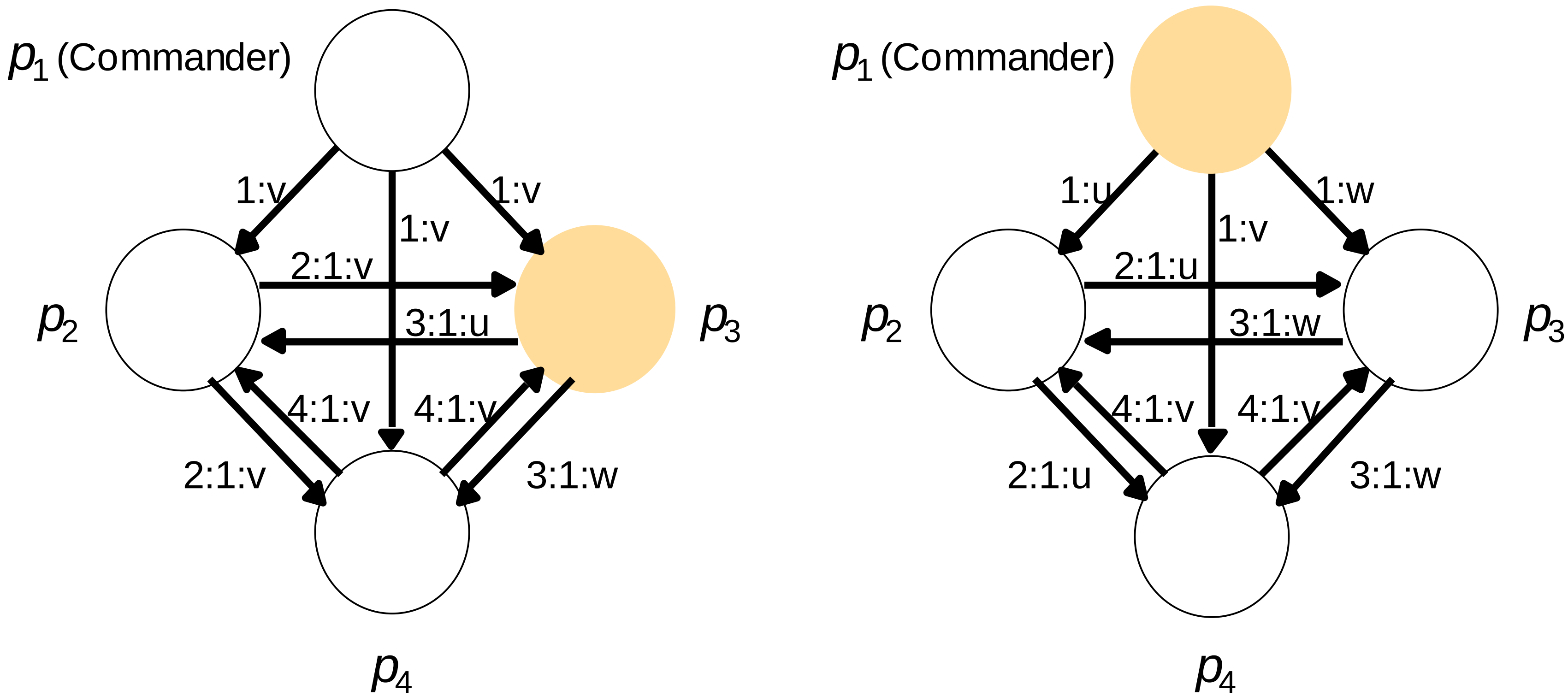
Assign $d_i = minimum(Values_i^{f+1})$;

Figure 15.18
Three Byzantine generals



Faulty processes are shown coloured

Figure 15.19
Four Byzantine generals



Faulty processes are shown coloured